ORNL/TM-2004/126

# Test Report for Cricket Radiation Detection System Used In EPA Port Installations

**June 2004**

**Prepared by**

**Ayman A. Shourbaji**
**Larry D. Phillips**
**Peter J. Chiaro, Jr.**

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**CONTENTS**

## EXECUTIVE SUMMARY

Oak Ridge National Laboratory conducted field radiological measurements at two port locations at the request of the Environmental Protection Agency (EPA). The radiological measurements were performed on five radiation detection systems at the port of Darrow, Louisiana and three systems at the port of Charleston, South Carolina. Darrow was visited on January 20-23, 2004 and Charleston on May 25, 2004.

All tested systems are designed to detect radioactive material that might be present in scrap metals as the scrap is being unloaded from ships. All eight systems are commercially known as the Cricket and manufactured by RAD/COMM Systems. Each radiation detection system consists of a detector with two channels and a wireless transmitter, both mounted on the grapple, and a controller located in the crane cab. The cranes at both locations are operated by the Cooper T. Smith Company.

The purpose of the radiological measurements was to evaluate the performance of the radiation detection systems in terms of their ability to detect elevated radiation levels, and to develop a routine testing method for all EPA Cricket systems.

## 1.0 INTRODUCTION

Oak Ridge National Laboratory (ORNL) conducted field radiological measurements at two port locations at the request of the Environmental Protection Agency (EPA). The radiological measurements were performed on five radiation detection systems at the port of Darrow, Louisiana (Darrow) and three systems at the port of Charleston, South Carolina (Charleston). Darrow was visited on January 20-23, 2004 and Charleston on May 25, 2004. All tested systems are designed to detect radioactive material that might be present in scrap metals as the scrap is being unloaded from ships. All eight Cricket systems are commercially available and manufactured by RAD/COMM Systems. Each radiation detection system consists of a two-channel (A & B) detection unit and a wireless transmitter, both mounted on the grapple, and a controller located in the crane cab. The cranes at both locations are operated by Cooper T. Smith Company.

Radiological measurements were made to evaluate the performance of the radiation detection systems in terms of their ability to detect elevated radiation levels in scrap steel, and to develop a routine testing method for all the EPA Cricket systems.

Two sets of data were collected for each system. One set is used for analyzing the alarm response of the detection system in order to compare it with a description of the alarm algorithm provided by RAD/COMM. The other set is used to analyze the detectors' sensitivity across its surface area.

Flow charts, developed by ORNL based on the RAD/COMM alarm algorithm are shown in Appendix A.

The alarm response and sensitivity measurements at Darrow were taken using a sealed $^{137}Cs$ (1.07 μCi as of August 8, 1984) source provided by the EPA. The alarm response and sensitivity measurements at Charleston were obtained using thoriated welding rod sources fabricated by Cooper T. Smith (~50 μrem/hr on contact).

Data collected from both sites are listed in Appendix B. Darrow data are listed in tables B1-B10, and Charleston data are listed in tables B11-B12.

## 2.0 FIELD TEST LOCATIONS & CRICKET SYSTEMS

The following is a list of the Cricket systems tested at each location:

- Darrow – Five Cricket systems installed on five grapples, and controlled and monitored by one control unit (RC/5) mounted in the cabin of crane # 1. Figure 1 is a functional block diagram illustrating the five Cricket radiation detection systems' arrangement.
    - Grapple # B3 (size 8 yards)
    - Grapple # B5 (size 11 yards)
    - Grapple # B6 (size 11 yards)
    - Grapple # B14 (size 17 yards)
    - Grapple # B51 (size 8 yards)

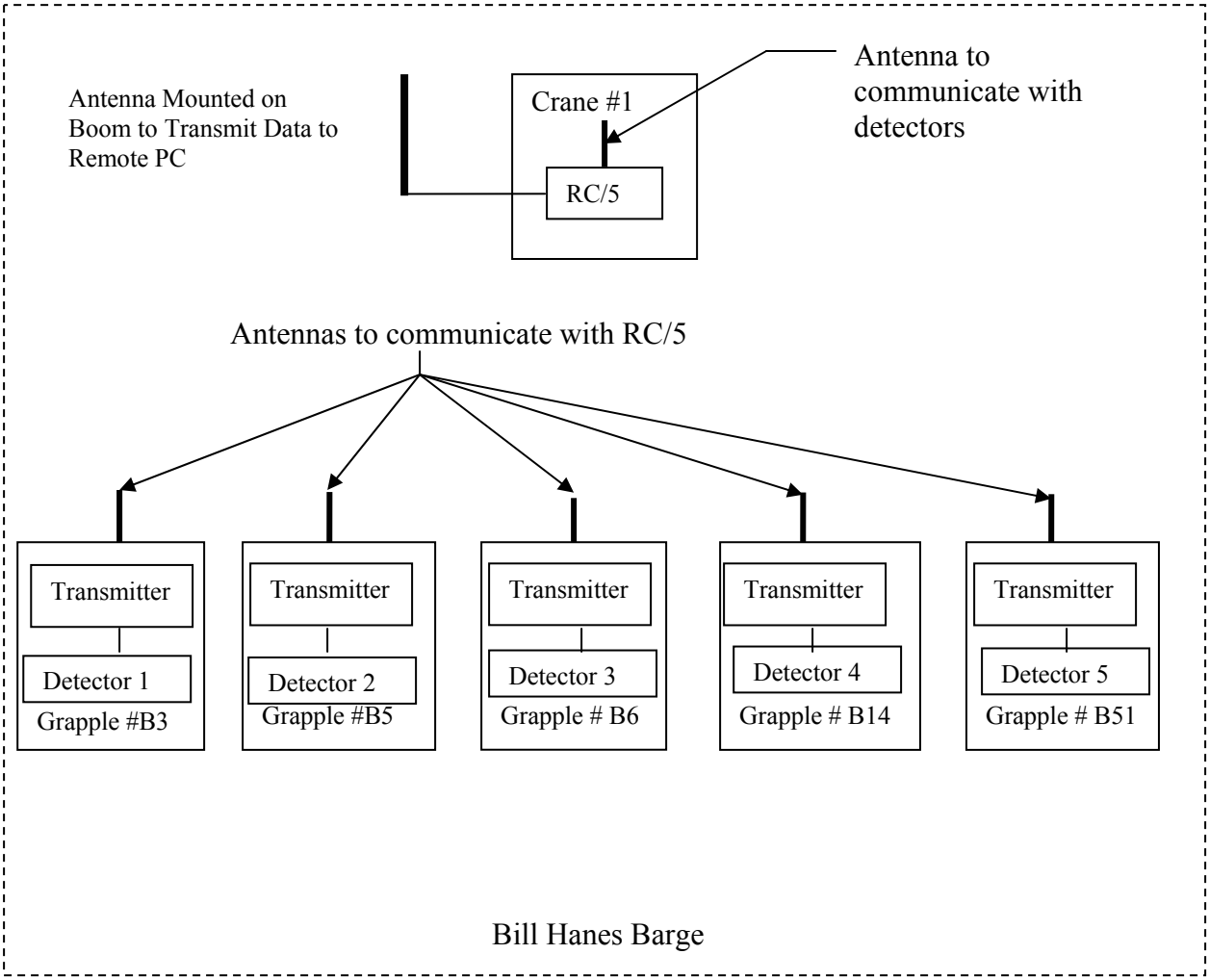


**Figure 1. Block Diagram Describing the Cricket Radiation Detection Systems at Darrow**

- Charleston - Three Cricket systems installed on three grapples, and controlled and monitored by one control unit (RC/5) mounted in the cabin of crane # 3. Figure 2 is a functional block diagram illustrating the three Cricket radiation detection systems' arrangement.
    - Grapple # 1 (size 10 yards)
    - Grapple # 2 (size 12 yards)
    - Grapple # 3 (size 12 yards)

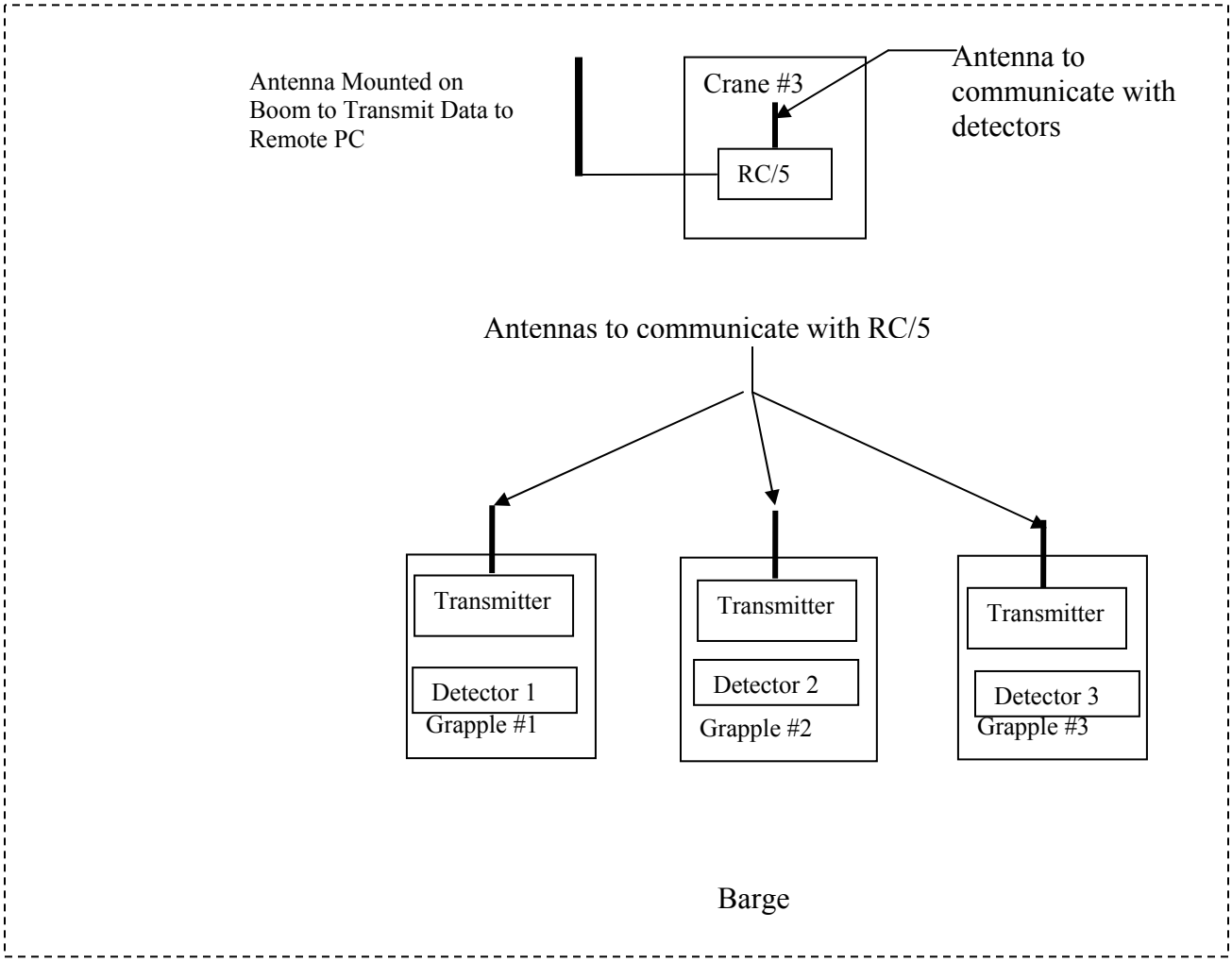


**Figure 2. Block Diagram Describing the Cricket Radiation Detection Systems at Charleston.**

## 3.0 TEST RESULTS

### 3.1 ALARM RESPONSE

The Cricket system is designed to provide the crane operator with seven alarm types as illustrated by the logic flow charts in Figures A1-A7. As shown in Appendix A, four of the alarms can be triggered with the grapple tines open or closed (R1, R2, RTK, RAB). The other three alarms are triggered upon the closing of the grapple tines (DAB, DSA, DAA). In addition, each alarm type is displayed along with its level which identifies the exposure rate in mR/hr. The Cricket detection system has five different levels (LVL1: less than 0.5mR/hr, LVL2: between 0.5 mR/hr and 1.0 mR/hr, LVL3: between 1.0 mR/hr and 2.0 mR/hr, LVL4: between 2.0 mR/hr and 5.0 mR/hr, LVL5: greater than 5.0 mR/hr) [1]. According to the number of levels (5) and the alarm types (7), it can be interpreted that the Cricket can generate 35 different alarms.

During alarm response testing, only one of the seven alarms was activated for all eight systems. This alarm was indicated as LVL1 # RAB and was triggered with the grapple tines in the open or closed position. The other six alarms were never observed during the tests described in this report.

At Darrow, the alarm response was tested for all five systems using a $^{137}$Cs source that produced alarms at an average of 400 net counts per second (cps). In an attempt to activate other alarms, 10 welding rods were used in addition to the $^{137}$Cs source to raise the count rate up to approximately 1400 cps. The same LVL1 # RAB alarm was triggered. This was tried on one system only.

At Charleston, the alarm response was tested for all three systems using 2 welding rod sources fabricated specifically for testing the Cricket systems. The average net count rate for the LVL1 # RAB alarm was 600 cps.

The background count rate and alarm type and count rate for Darrow and Charleston are tabulated in Table 1. In addition, the detectable limit (DL) for each location has been computed and shown in Table1. The DL is a measure of the statistical significance of the detection process at each location based on the background. A measured net count rate higher than the DL value indicates a high confidence level, typically 90% according to the way DL is computed [2]. This quantity is not related to the quality of the detection system but to the statistically random nature of radioactive decay and the measurement itself. The DL for Darrow based on the measured ambient background (62 cps) is 40 cps. The DL for Charleston based on the measured ambient background (51 cps) is 36 cps. Accordingly, the estimated sensitivity level in activity should be expressed by taking into consideration the detection efficiency as follows:

Activity level (dps) = Net Counts (cps) / E

Where,

E is the detection efficiency of the Cricket system, and
dps is the activity in disintegration per second which can be converted to Curie (Ci) by the relation:

1 Ci = $3.7e^{10}$ dps.

## 3.2 OBSERVATIONS

1. The measured ambient background at Darrow and Charleston, which is in the range of 60 cps, can be considered as the normal ambient for both locations. Background significantly higher than 60 cps can be considered abnormal and should be investigated.

2. The background for channel B associated with the Cricket system installed on Grapple B3 at Darrow was high. The background for this channel was 238 cps which is approximately four times higher than channel A of the same system as well as the four other systems.

3. The position of the RC/5 controller inside the crane cabin requires the operator to turn his attention away from operating the crane during loading/unloading scrap in order to observe the alarm display. There is also the potential of background noise masking the audible alarm which would prevent the operator from hearing the alarm.

4. Analysis of the alarm algorithm for the Cricket system shows a high degree of complexity for the intended operation as illustrated by the flow diagrams (Figure A1-A7). The flow diagrams were developed by ORNL from a written description of the alarm algorithms provided by RAD/COMM. The system has seven alarm types and five alarm levels associated with each alarm type. It is not clear as to why they are needed and for what purpose. During the entire testing effort only one alarm type was observed (LVL1 #RAB) at both locations. Considering the operators' interaction with the Cricket system and the need to know, these various alarms are confusing and don't add any value. The operator only needs to know if the load of scrap has an elevated radiation level. This can be presented to the operator in a simple go/no-go fashion. Interaction with the RC/5 controller requires someone who is more technically oriented.

5. Careful consideration should be given to interpreting the exposure rates indicated by the alarm levels (LVL1-LVL5). Exposure rates in R/hr are typically measured at a certain distance from the radiation source. Varying the distance between the source and the measurement point will certainly vary the exposure. Such a relationship is governed by the inverse square law:

   $$\text{Exposure at distance d2} = \text{Exposure at d1}\left(\frac{d1}{d2}\right)^2$$

## 3.3 MEASUREMENT SENSITIVITY

The analysis of the sensitivity data collected from both sites (Tables B1-B13) indicates that optimal measurement can be obtained at the center of each detector channel. As shown by Figure 3, placing the radioactive source at location A2 and B2 provides the highest count rate compared to the other locations (A1, A3, B1, B3, and C). Unfortunately, readings from the center will not provide a complete indication of the detector's status. In order to detect changes in detection quality it is critical to challenge the detector by placing the source at the farthest point from the photomultiplier tube. Cracks or other degradations would be indicated by reduced count rates when tests are performed at that location. These changes may not be as apparent when testing the detector by placing the source at a location that is nearer to the photomultiplier tube (PMT).

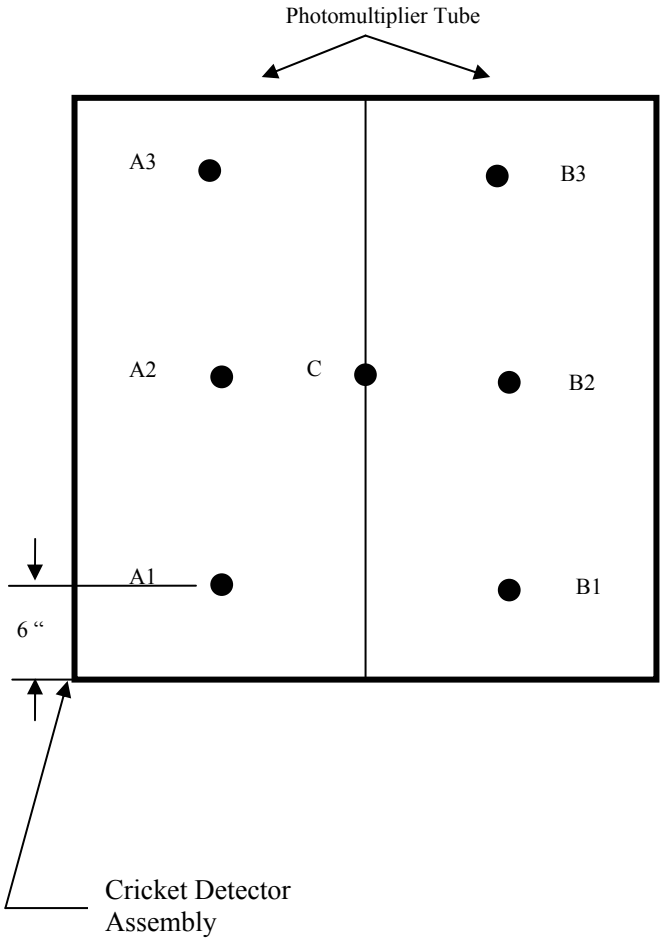


**Figure 3. Cricket Detector Assembly Illustrating Sensitivity Measurements Locations**

Therefore, ORNL recommends using location A1 & B1 for routine testing of the Cricket systems. Measurement points A1 & B1 are located along the center line of each channel at 6 inches from the edge of the detector's housing farthest from the PMT as illustrated by Figure 3.

**Table 1**. **Darrow & Charleston Alarm Data**

| **Measurement (CPS)** | **Darrow** | **Charleston** |
|---|---|---|
| Average Background* | 62 | 51 |
| Average Alarm Total Count** | 465 | 650 |
| Average Alarm Net Count* | 403 | 599 |
| Alarm Type | LVL1 # RAB | LVL1 #RAB |
| Detectable Limit (DL)*** | 40 | 36 |

* Excluding channel B for Grapple B3
** Average count for all systems per location *** DL = (3 + 4.65 * √BKG)/Count Time) [2]

## 4.0 RECOMMENDATIONS

Based on the test results, observations by ORNL during testing, and discussions with Cooper T. Smith operators, ORNL offers the following recommendations:

- It is recommended to place the test source at points A1 & B1 shown in Figure 3 to obtain the best results for routine testing of detectors' performance. ORNL has developed a routine test tracking web site (http://public.ornl.gov/estd/qc/) that could be used as a simple tracking method for response results. It is recommended that response tests be performed at least weekly. The range should be based on the average reading from each detector with a tolerance of ± 20%.

- Sources should be standardized for testing the Cricket systems installed at both locations (Darrow and Charleston), as well as any future applications at other EPA sites. It is recommended to use a source similar to that being used at Charleston. This would mitigate the need for special training and certification required for handling radioactive sources, maintaining survey meters, and establishing site specific QA procedures to handle and store sources.

- The high background reading for channel B for the Cricket system installed in Grapple B3 needs to be investigated to determine the cause. The background reading for channel B was 238 counts. This is four times higher than all other detectors.

- Wiring connectors from the battery box to the detector at Darrow need to be replaced with connectors similar to those used at Charleston to prevent corrosion. This will help in reducing maintenance efforts and the spare parts inventory.

- Consideration should be given to provide a simple visual indication for the crane operator with the RC/5 acting as the controller (see Figure 4). The display unit could be as simple as a visual display with two indicators, red and green, located in the vicinity of the crane's operator console. Red would indicate an increase in radiation levels and green would indicate clean load. The RC/5, on the other hand, can be used by a technical person.

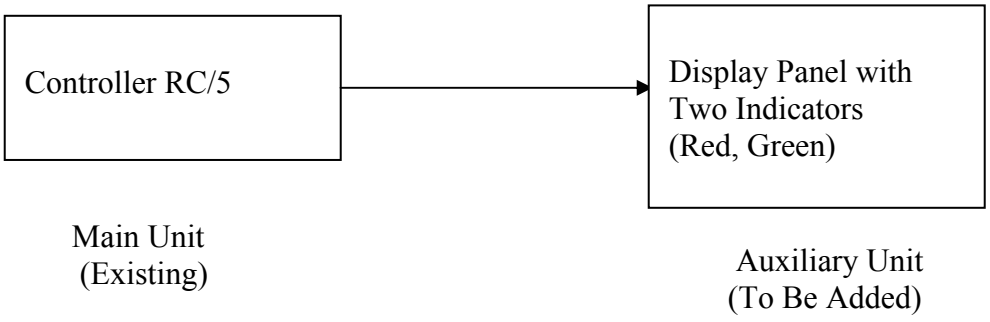


**Figure 4. ORNL Suggested Operator Interaction Configuration**

- The alarm algorithm for the Cricket system needs to be simplified. Operationally, the Cricket should provide the crane operator with a simple alarm telling the operator how to process the load of scrap. Any further details concerning the nature of the radiation should be undertaken by someone other than the crane operator.

## REFERENCES

1. RAD/COMM, ‘Cricket Operations Manual’

2. University of Toronto, ‘Module6: Radiation Detection and Measurements’, http://www.utoronto.ca/safety/RadTraining/Module6.htm

**APPENDIX A**
**ALARM FLOW DIAGRAM FOR THE CRICKET SYSTEM**

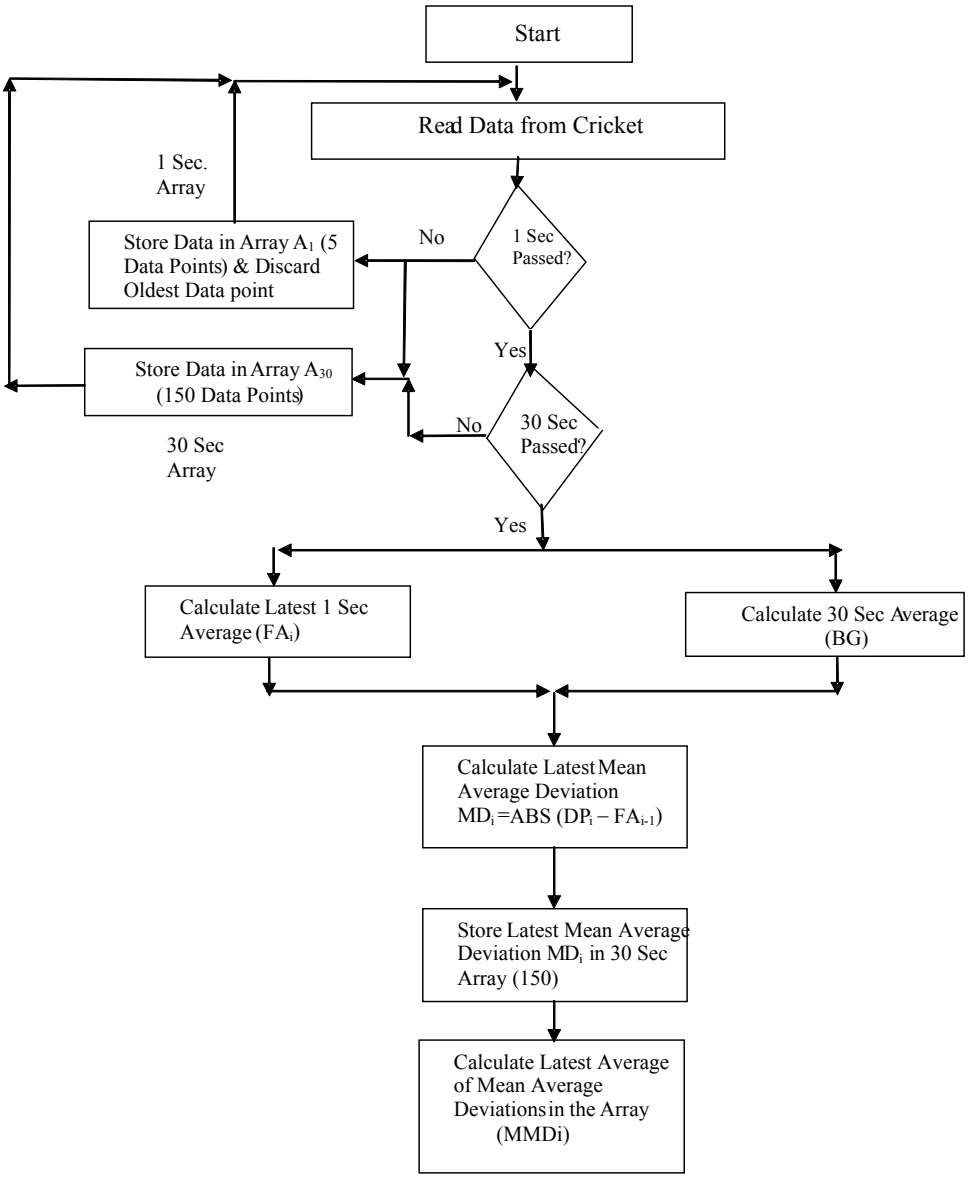


**Figure A1**. Logic Flow Diagram for Initializing Alarm Algorithms

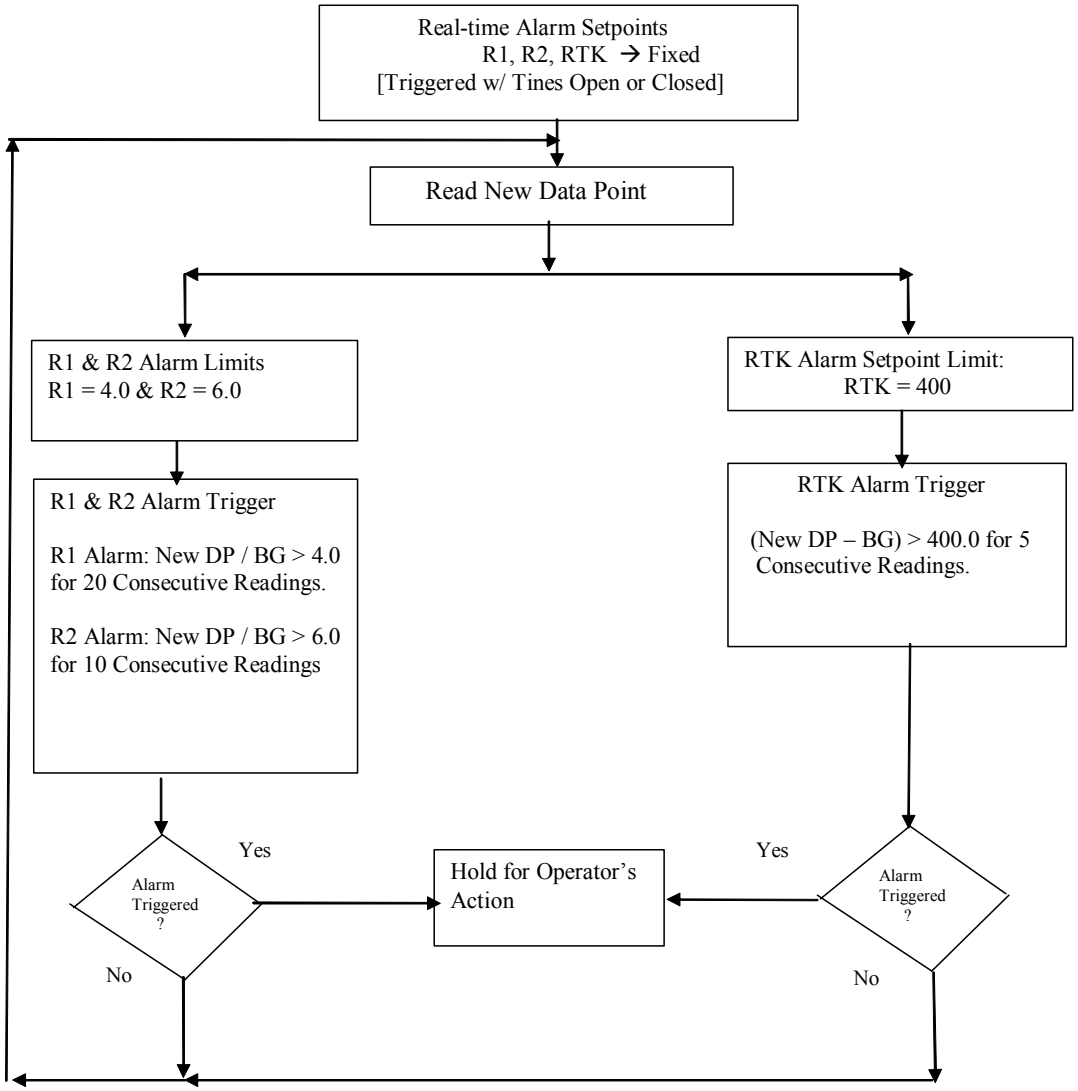


**Figure A2**. Logic Flow Diagram for Real Time Alarms (R1, R2, RTK)

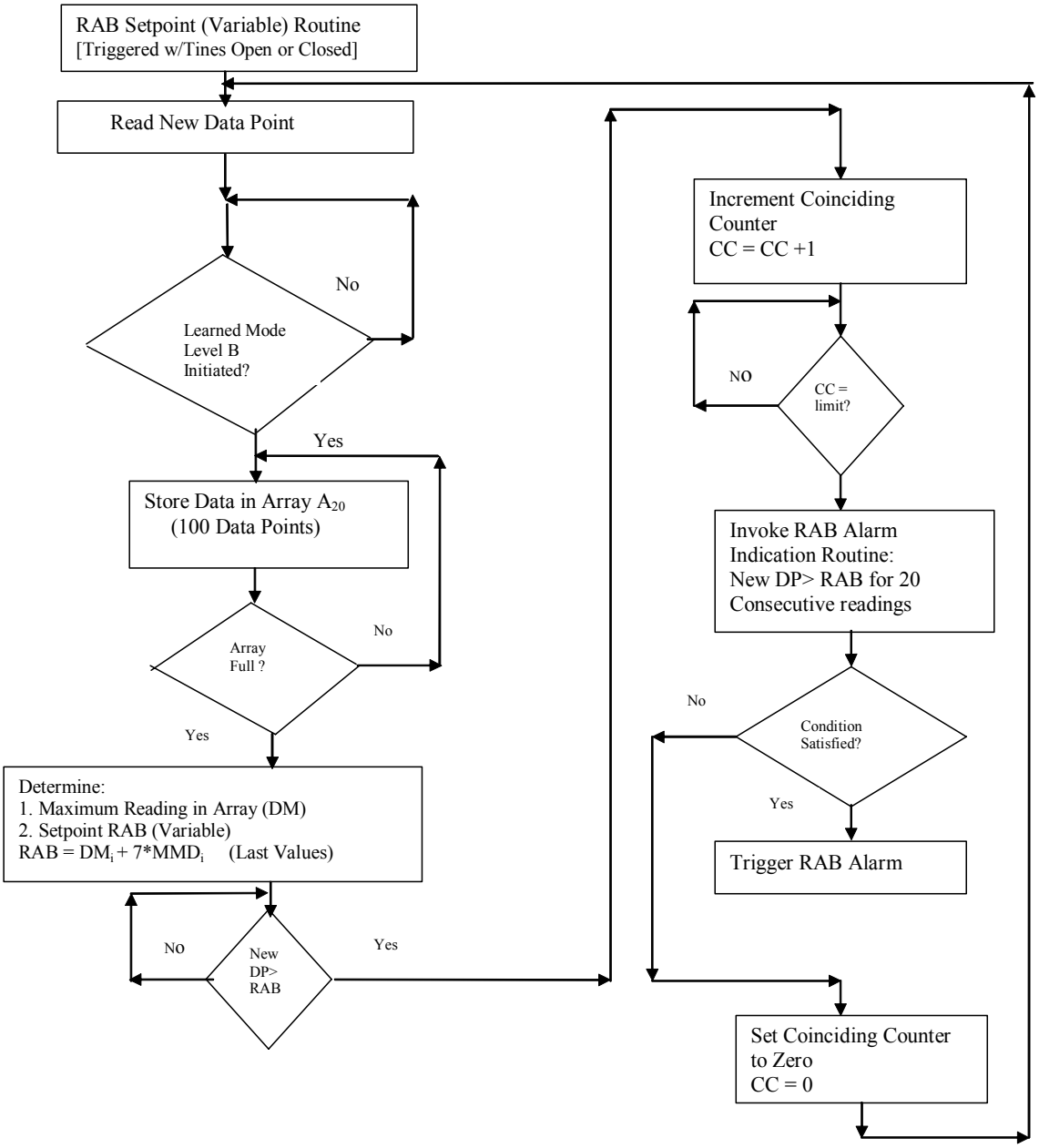


**Figure A3**. Logic Flow Diagram for RAB Alarm Routine.

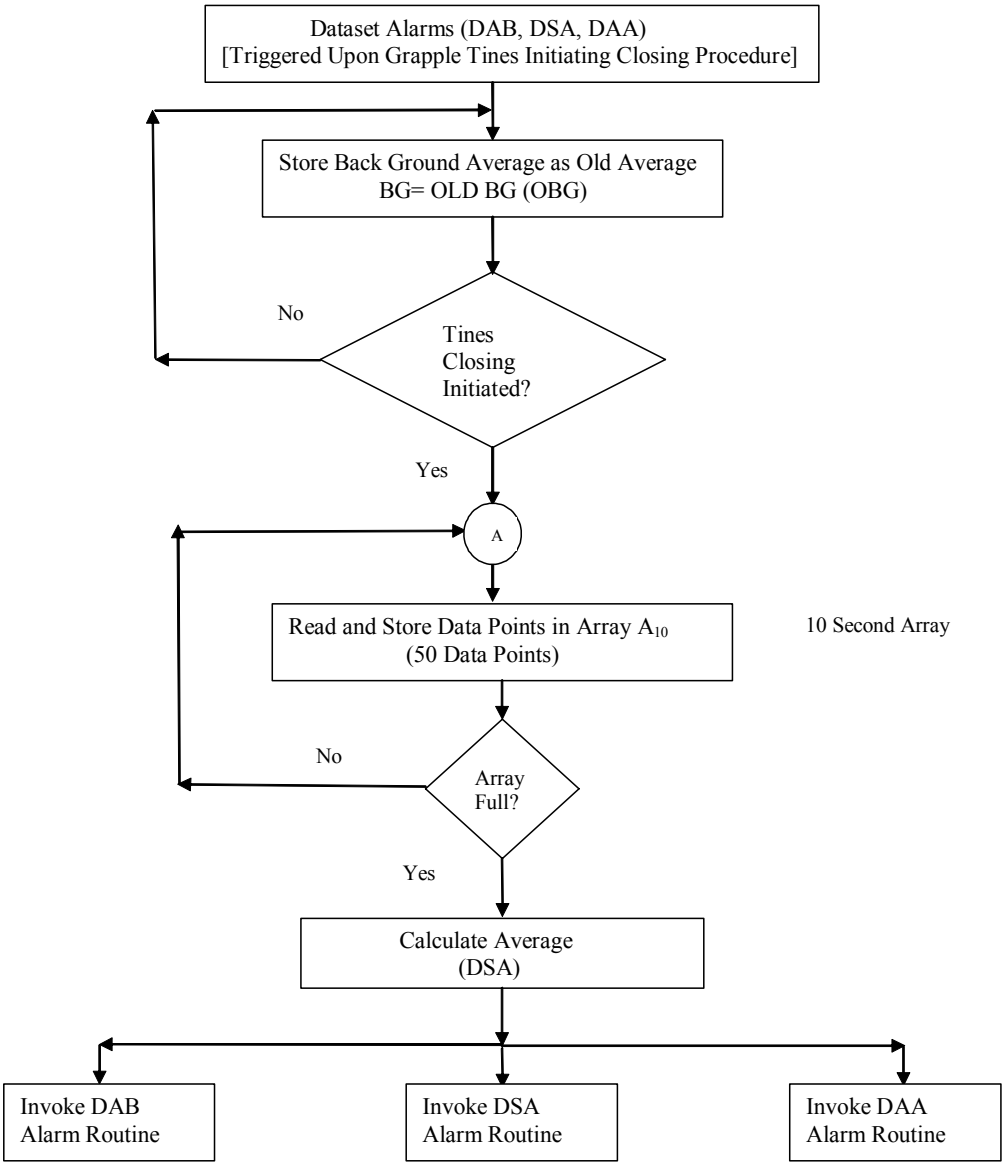


**Figure A4**. Logic Flow Diagram for Invoking Alarms (DAB, DSA, DAA) Initiated Upon Tines Closing.

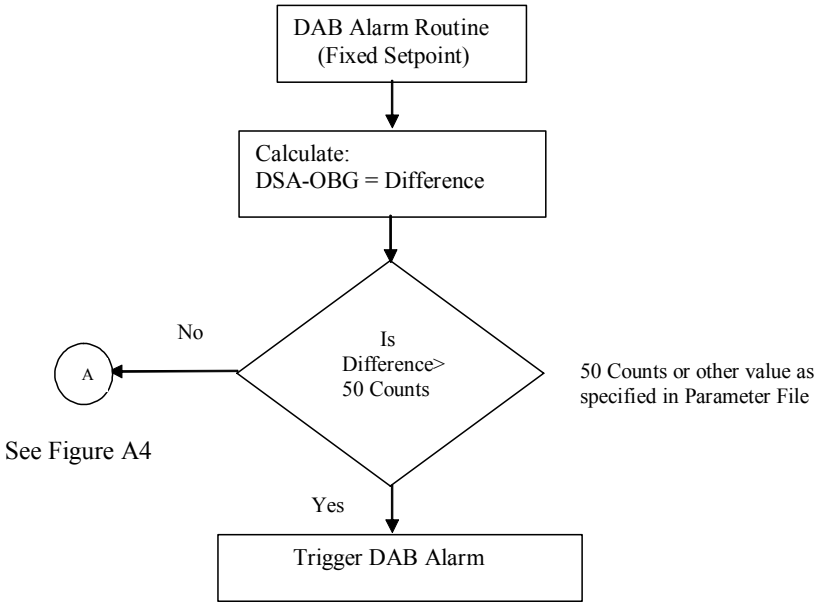


**Figure A5**. Logic Flow Diagram for Triggering DAB Alarm

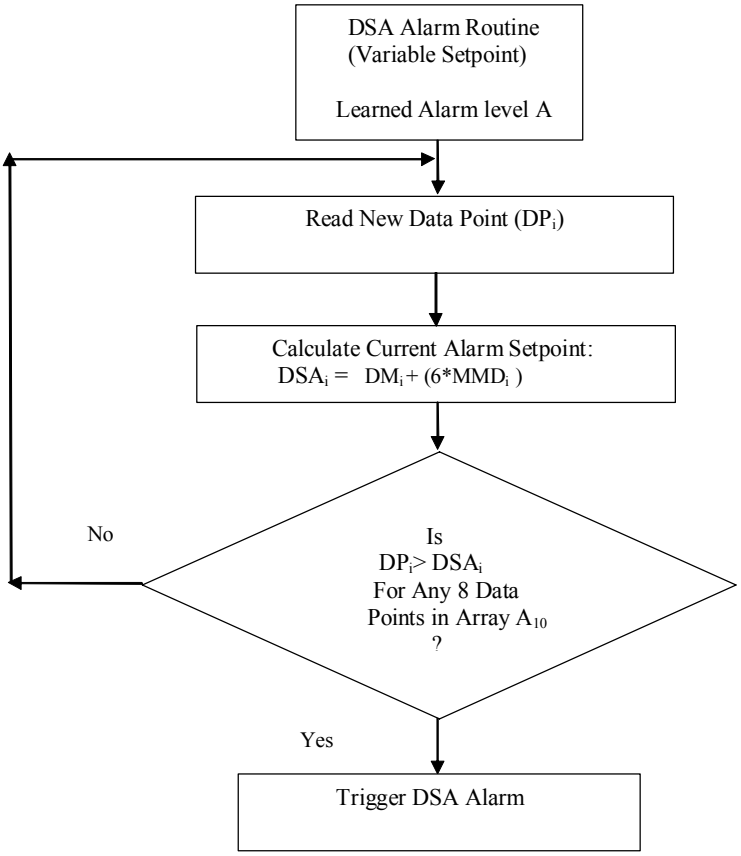


**Figure A6**. Logic Flow Diagram for Triggering DSA Alarm.

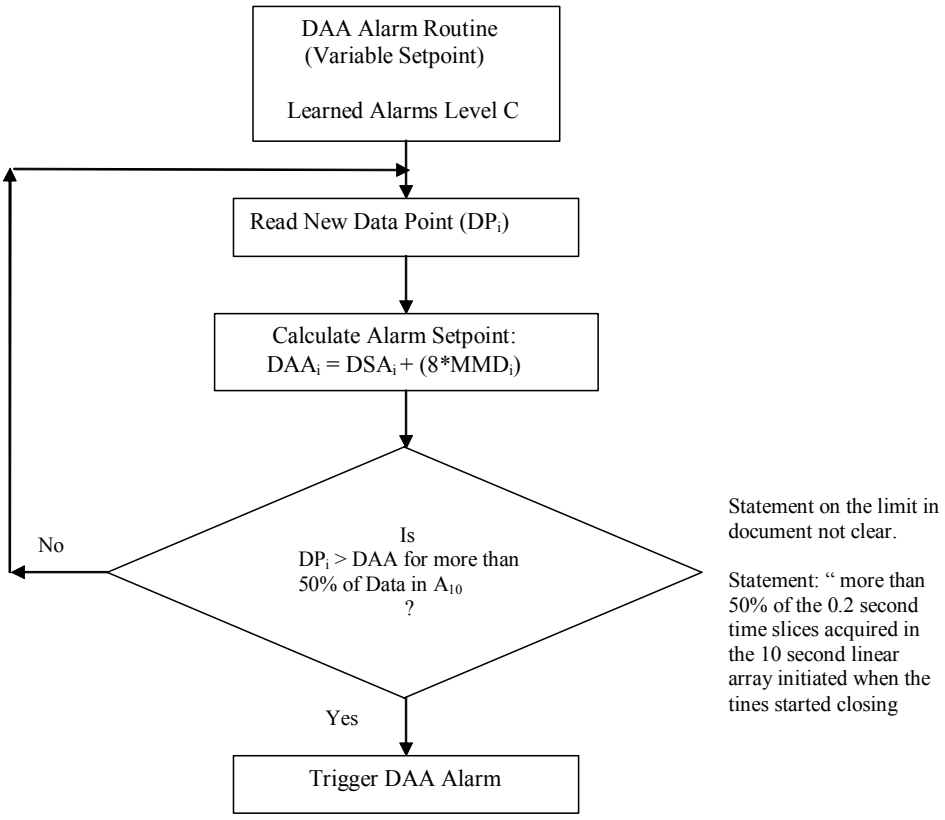


**Figure A7**. Logic Flow Diagram for Triggering DAA Alarm.

# APPENDIX B
# TEST RESULTS FOR DARROW AND CHARLESTON

## Figure B1. DARROW Alarm Response Test (Grapple B3)

**Date:** 1/22/04
**Cricket System ID**: Darrow/Bill Hines/Grapple B3/Transmitter 2
**Test Source**: Cs-137, Activity 1.07 uCi, Dateed 8/8/84
**Weather Conditions**: Sunny, ~45-50 $^{o}$F
**Performed By**: Ayman Shourbaji & Larry Phillips

| | Back Ground | | |
|---|---|---|---|
| | **Det A** | **Det B** | **Total(T)** |
| | 91 | 242 | 300 |
| | 86 | 227 | 318 |
| | 51 | 273 | 316 |
| | 116 | 247 | 312 |
| | 71 | 202 | 308 |
| **Average** | **83** | **238** | **311** |

| Tines Open | | | | Tines Closed | | | |
|---|---|---|---|---|---|---|---|
| **Alarm Type** | **A (CPM)*** | **B (CPM)*** | **Remarks** | **Alarm Type** | **A (CPM)*** | **B (CPM)*** | **Remarks** |
| Level 1/RAB | 449 | 606 | A & B alarms | Level1/RAB | 449 | | A & B alarms |
| | 414 | 717 | level 1 /RAB | | 553 | 409 | level 1 / RAB |
| | 459 | 657 | | | 485 | 348 | |
| | 510 | 667 | | | 596 | 338 | |
| | 444 | 591 | | | 550 | 419 | |
| | 455 | 682 | | | 556 | 455 | |
| | 505 | 732 | | | 429 | 444 | |
| | 399 | 707 | | | 399 | 364 | |
| | 515 | 697 | | | 449 | 460 | |
| | 510 | 657 | | | 434 | 455 | |
| **Average** | **466** | **671** | | **Average** | **490** | **410** | |

* Measurements for A & B were obtained separately

## Figure B2. DARROW Sensitivity Test (Grapple B3)

**Date:** 1/22/04
**Cricket System ID**: Darrow/Bill Hines/Grapple B3/Transmitter 2
**Test Source**: Cs-137, Activity 1.07 uCi, 8/8/84
**Weather Conditions:** Sunny, ~45-50 $^{o}$F
**Performed By**: Ayman Shourbaji & Larry Phillips

| | Back Ground | | |
|---|---|---|---|
| | **Det A** | **Det B** | **Total (T)** |
| | 91 | 242 | 300 |
| | 86 | 227 | 318 |
| | 51 | 273 | 316 |
| | 116 | 247 | 312 |
| | 71 | 202 | 308 |
| **Average** | **83** | **238** | **311** |

| See Sketch #1 for Measurement Locations | | | | | |
|---|---|---|---|---|---|
| **A1** | **A2** | **A3** | **B1** | **B2** | **B3** |
| 495 | 712 | 692 | 611 | 889 | 581 |
| 424 | 783 | 591 | 722 | 808 | 591 |
| 530 | 692 | 682 | 621 | 783 | 651 |
| 510 | 853 | 667 | 616 | 838 | 571 |
| 449 | 682 | 606 | 601 | 783 | 606 |
| 389 | 879 | 535 | 581 | 788 | 636 |
| 444 | 727 | 505 | 566 | 722 | 631 |
| 510 | 702 | 550 | 657 | 813 | 657 |
| 359 | 838 | 677 | 722 | 823 | 545 |
| 419 | 707 | 495 | 662 | 758 | 651 |
| **453** | **758** | **600** | **636** | **801** | **612** |

| See Sketch #1 for Measurement Locations | | | |
|---|---|---|---|
| **C0 (T)** | **C6 (T)** | **C12 (T)** | **C36(T)** |
| 611 | 638 | 605 | 380 |
| 610 | 637 | 611 | 382 |
| 604 | 638 | 614 | 396 |
| 610 | 634 | 612 | 395 |
| 609 | 643 | 608 | 397 |
| 612 | 639 | 610 | 398 |
| 610 | 643 | 612 | 394 |
| 613 | 647 | 608 | 396 |
| 617 | 645 | 611 | 400 |
| 614 | 647 | 609 | 395 |
| **611** | **641** | **610** | **393** |

C0 (T) denotes measurement taken at point C w/ source placed against the detector and readings taken from channel T

C6 (T) denotes measurement taken at point C w/ source 6" from the detector and readings taken from channel T

C12 (T) denotes measurement taken at point C w/source 12" from the detecor and readings taken from channel T.

C36 (T) denotes measurement taken at point C w/source 36" from the detecor and readings taken from channel T.

## Figure B3. DARROW Alarm Response Test (Grapple B5)

**Date:** 1/21/04
**Cricket System ID**: Darrow/Bill Hines/Grapple B5/Transmitter 1
**Test Source**: Cs-137, Activity 1.07 uCi, 8/8/84
**Weather Conditions:** Sunny, ~45-50 $^{o}$F
**Performed By**: Ayman Shourbaji & Larry Phillips

| | Back Ground | | |
|---|---|---|---|
| | **Det A** | **Det B** | **Total (T)** |
| | 66 | 45 | 114 |
| | 71 | 51 | 116 |
| | 51 | 61 | 118 |
| | 101 | 35 | 117 |
| | 36 | 76 | 113 |
| **Average** | **65** | **54** | **116** |

| | Tines Open | | | | Tines Closed | | |
|---|---|---|---|---|---|---|---|
| **Alarm Type** | **A (CPM)*** | **B (CPM)*** | **Remarks** | **Alarm Type** | **A (CPM)*** | **B (CPM)*** | **Remarks** |
| Level1/RAB | 530 | 460 | A & B alarms | Level 1/ RAB | 510 | 354 | A & B alarms |
| | 505 | 444 | level 1/RAB | | 455 | 424 | level 1/RAB |
| | 485 | 414 | | | 424 | 384 | |
| | 500 | 424 | | | 434 | 384 | |
| | 485 | 313 | | | 444 | 348 | |
| | 515 | 374 | | | 439 | 399 | |
| | 500 | 419 | | | 465 | 434 | |
| | 601 | 323 | | | 384 | 313 | |
| | 505 | 485 | | | 434 | 455 | |
| | 596 | 420 | | | 430 | 451 | |
| **Average** | **522** | **408** | | **Average** | **442** | **395** | |

* Measurements for A & B were obtained separately

## Figure B4. DARROW Sensitivity Test (Grapple B5)

**Date:** 1/21/04
**Cricket System ID**: Darrow/Bill Hines/Grapple B5/Transmitter 1
**Test Source**: Cs-137, Activity 1.07 uCi, 8/8/84
**Weather Conditions:** Sunny, ~45-50 $^{o}$F
**Performed By**: Ayman Shourbaji & Larry Phillips

| | Back Ground | | |
|---|---|---|---|
| | **Det A** | **Det B** | **Total (T)** |
| | 66 | 45 | 114 |
| | 71 | 51 | 116 |
| | 51 | 61 | 118 |
| | 101 | 35 | 117 |
| | 36 | 76 | 113 |
| **Average** | **65** | **54** | **116** |

| See Sketch #1 for Measurement Locations | | | | | |
|---|---|---|---|---|---|
| **A1** | **A2** | **A3** | **B1** | **B2** | **B3** |
| 419 | 828 | 626 | 207 | 500 | 394 |
| 409 | 818 | 682 | 263 | 354 | 424 |
| 359 | 672 | 681 | 202 | 475 | 364 |
| 439 | 758 | 687 | 268 | 510 | 303 |
| 424 | 768 | 581 | 152 | 485 | 294 |
| 394 | 732 | 758 | 232 | 424 | 333 |
| 364 | 631 | 651 | 202 | 470 | 364 |
| 404 | 793 | 768 | 217 | 485 | 419 |
| 389 | 838 | 763 | 278 | 505 | 308 |
| 354 | 756 | 667 | 202 | 419 | 333 |
| **396** | **759** | **686** | **222** | **463** | **354** |

| See Sketch #1 for Measurement Locations | | |
|---|---|---|
| **C0 (T)** | **C6 (T)** | **C12 (T)** |
| 277 | 241 | 331 |
| 270 | 268 | 319 |
| 273 | 291 | 323 |
| 284 | 299 | 324 |
| 295 | 334 | 336 |
| 304 | 345 | 361 |
| 318 | 367 | 386 |
| 325 | 391 | 412 |
| 315 | 446 | 440 |
| 318 | 438 | 456 |
| **298** | **342** | **369** |

C0 (T) denotes measurement taken at point C w/ source placed against the detector and readings taken from channel T

C6 (T) denotes measurement taken at point C w/ source 6" from the detector and readings taken from channel T

C12 (T) denotes measurement taken at point C w/source 12" from the detecor and readings taken from channel T.

## Figure B5. DARROW Alarm Response Test (Grapple B6)

**Date:** 1/22/04
**Cricket System ID**: Darrow/Bill Hines/Grapple B6/Transmitter 2
**Test Source**: Cs-137, Activity 1.07 uCi, 8/8/84
**Weather Conditions:** Sunny, ~45-50 $^{o}$F
**Performed By**: Ayman Shourbaji & Larry Phillips

| | Back Ground | | |
|---|---|---|---|
| | **Det A** | **Det B** | **Total (T)** |
| | 61 | 56 | 88 |
| | 40 | 25 | 89 |
| | 45 | 51 | 90 |
| | 66 | 20 | 92 |
| | 76 | 40 | 94 |
| **Average** | **58** | **38** | **91** |

| Tines Open | | | | Tines Closed | | | |
|---|---|---|---|---|---|---|---|
| **Alarm Type** | **A (CPM)*** | **B (CPM)*** | **Remarks** | **Alarm Type** | **A (CPM)*** | **B (CPM)*** | **Remarks** |
| Level1/RAB | 419 | 651 | A & B alarms | Level 1/ RAB | 535 | 449 | A & B alarms |
| | 485 | 557 | level 1/RAB | | 566 | 525 | level 1/RAB |
| | 394 | 712 | | | 586 | 495 | |
| | 389 | 631 | | | 591 | 399 | |
| | 343 | 576 | | | 495 | 394 | |
| | 364 | 550 | | | 722 | 323 | |
| | 374 | 586 | | | 465 | 434 | |
| | 343 | 545 | | | 475 | 525 | |
| | 429 | 571 | | | 515 | 404 | |
| | 379 | 672 | | | 470 | 495 | |
| **Average** | **392** | **605** | | **Average** | **542** | **444** | |

## Figure B6. DARROW Sensitivity Test (Grapple B6)

**Date:** 1/22/04
**Cricket System ID**: Darrow/Bill Hines/Grapple B6/Transmitter 2
**Test Source**: Cs-137, Activity 1.07 uCi, 8/8/84
**Weather Conditions:** Sunny, ~45-50 $^{o}$F
**Performed By**: Ayman Shourbaji & Larry Phillips

| | Back Ground | | |
|---|---|---|---|
| | **Det A** | **Det B** | **Total (T)** |
| | 61 | 56 | 88 |
| | 40 | 25 | 89 |
| | 45 | 51 | 90 |
| | 66 | 20 | 92 |
| | 76 | 40 | 94 |
| **Average** | **58** | **38** | **91** |

| See Sketch #1 for Measurement Locations | | | | | |
|---|---|---|---|---|---|
| **A1** | **A2** | **A3** | **B1** | **B2** | **B3** |
| 217 | 581 | 597 | 490 | 687 | 601 |
| 152 | 576 | 439 | 626 | 742 | 641 |
| 182 | 636 | 500 | 545 | 747 | 778 |
| 202 | 646 | 561 | 576 | 778 | 717 |
| 217 | 601 | 505 | 439 | 758 | 768 |
| 222 | 626 | 465 | 384 | 778 | 732 |
| 242 | 727 | 480 | 449 | 747 | 621 |
| 207 | 566 | 434 | 434 | 727 | 662 |
| 167 | 621 | 475 | 505 | 737 | 677 |
| 177 | 651 | 460 | 419 | 621 | 722 |
| **199** | **623** | **492** | **487** | **732** | **692** |

| See Sketch #1 for Measurement Locations | | | |
|---|---|---|---|
| **C0 (T)** | **C6 (T)** | **C12 (T)** | **C36(T)** |
| 468 | 457 | 450 | 212 |
| 467 | 458 | 451 | 210 |
| 466 | 465 | 452 | 213 |
| 468 | 468 | 448 | 212 |
| 461 | 467 | 449 | 211 |
| 453 | 466 | 451 | 212 |
| 441 | 478 | 452 | 213 |
| 447 | 484 | 434 | 215 |
| 454 | 481 | 441 | 214 |
| 466 | 485 | 438 | 212 |
| **459** | **471** | **447** | **212** |

C0 (T) denotes measurement taken at point C w/ source placed against the detector and readings taken from channel T

C6 (T) denotes measurement taken at point C w/ source 6" from the detector and readings taken from channel T

C12 (T) denotes measurement taken at point C w/source 12" from the detecor and readings taken from channel T.

C136 (T) denotes measurement taken at point C w/source 36" from the detecor and readings taken from channel T.

## Figure B7. DARROW Alarm Response Test (Grapple B14)

**Date:** 1/21/04
**Cricket System ID**: Darrow/Bill Hines/Grapple B14/Transmitter 5
**Test Source**: Cs-137, Activity 1.07 uCi
**Weather Conditions:** Sunny, 45-50 $^{o}$F
**Performed By**: Ayman Shourbaji & Larry Phillips

| | Back Ground | |
|---|---|---|
| | Det A | Det B |
| | 91 | 76 |
| | 71 | 61 |
| | 56 | 71 |
| | 45 | 66 |
| | 66 | 111 |
| **Average** | **66** | **77** |

| Tines Open | | | | Tines Closed | | | |
|---|---|---|---|---|---|---|---|
| **Alarm Type** | **A (CPM)*** | **B (CPM)*** | **Remarks** | **Alarm Type** | **A (CPM)*** | **B (CPM)*** | **Remarks** |
| Level 1/RAB | 424 | 449 | A & B alarms | Level1/RAB | 465 | 394 | A & B alarms |
| | 338 | 444 | level 1/RAB | | 444 | 409 | level 1/RAB |
| | 424 | 566 | | | 389 | 348 | |
| | 460 | 434 | | | 470 | 338 | |
| | 444 | 505 | | | 475 | 419 | |
| | 399 | 465 | | | 460 | 455 | |
| | 354 | 490 | | | 384 | 444 | |
| | 389 | 399 | | | 475 | 364 | |
| | 369 | 465 | | | 465 | 460 | |
| | 375 | 460 | | | 462 | 455 | |
| **Average** | **398** | **468** | | **Average** | **449** | **409** | |

* Measurements for A & B were obtained separately

## Figure B8. DARROW Sensitivity Test (Grapple B14)

**Date:** 1/21/04
**Cricket System ID**: Darrow/Bill Hines/Grapple B14/Transmitter 5
**Test Source**: Cs-137, Activity 1.07 uCi, Dated 8/8/84
**Weather Conditions:** Sunny, 45-50 $^{o}$F
**Performed By**: Ayman Shourbaji & Larry Phillips

| | Back Ground | |
|---|---|---|
| | **Det A** | **Det B** |
| | 91 | 76 |
| | 71 | 61 |
| | 56 | 71 |
| | 45 | 66 |
| | 66 | 111 |
| **Average** | **66** | **77** |

| See Sketch #1 for Measurement Locations | | | | | |
|---|---|---|---|---|---|
| **A1** | **A2** | **A3** | **B1** | **B2** | **B3** |
| 455 | 636 | 697 | 515 | 823 | 571 |
| 419 | 621 | 667 | 449 | 576 | 626 |
| 409 | 682 | 672 | 465 | 778 | 687 |
| 510 | 727 | 621 | 490 | 803 | 707 |
| 429 | 692 | 626 | 455 | 914 | 682 |
| 475 | 631 | 556 | 475 | 848 | 747 |
| 404 | 693 | 611 | 571 | 838 | 838 |
| 384 | 702 | 490 | 465 | 798 | 732 |
| 409 | 742 | 550 | 460 | 727 | 793 |
| 439 | 752 | 586 | 444 | 894 | 758 |
| **433** | **688** | **608** | **479** | **800** | **714** |

| See Sketch #1 for Measurement Locations | | | |
|---|---|---|---|
| **C0 (T)** | **C6 (T)** | **C12 (T)** | **C24 (T)** |
| 355 | 543 | 566 | 316 |
| 356 | 542 | 552 | 310 |
| 355 | 537 | 550 | 312 |
| 352 | 538 | 553 | 313 |
| 357 | 537 | 554 | 315 |
| 354 | 530 | 553 | 319 |
| 353 | 561 | 551 | 317 |
| 352 | 558 | 547 | 314 |
| 350 | 557 | 544 | 315 |
| 347 | 552 | 542 | 316 |
| **353** | **546** | **551** | **315** |

C0 (T) denotes data taken at point C w/ source placed against detector and readings taken from Channel T

C6 (T) denotes data taken at point C w/ source placed 6" from detector and readings taken from Channel T

C12 (T) denotes data taken at point C w/ source placed 12" from detector and readings taken from Channel T

C24" (T) denotes data taken at point C w/ source placed 24" from detector and readings taken from Channel T

## Figure B9. DARROW Alarm Response Test (Grapple B51)

**Date**: 1/21/04
**Cricket System ID**: Darrow/Grapple B51/Transmitter 5
**Test Source**: Cs-137, Activity 1.07 uCi
**Weather Conditions:** Sunny, ~ 45-50 $^{o}$F,
**Performed By**: Ayman Shourbaji & Larry Phillips

| | Back Ground | | |
|---|---|---|---|
| | **Det A** | **Det B** | **Total (T)** |
| | 56 | 45 | 114 |
| | 40 | 51 | 116 |
| | 76 | 40 | 118 |
| | 91 | 56 | 117 |
| | 71 | 51 | 113 |
| **Average** | **67** | **49** | **116** |

| Tines Open | | | | Tines Closed | | | |
|---|---|---|---|---|---|---|---|
| **Alarm Type** | **A (CPM)*** | **B (CPM)*** | **Remarks** | **Alarm Type** | **A (CPM)*** | **B (CPM)*** | **Remarks** |
| Level1/RAB | 530 | 485 | A & B alarms | Level 1/ RAB | 455 | 429 | A & B alarms |
| | 485 | 429 | level 1/ RAB | | 429 | 439 | level 1/ RAB |
| | 394 | 500 | | | 424 | 455 | |
| | 444 | 444 | | | 475 | 490 | |
| | 434 | 399 | | | 414 | 404 | |
| | 394 | 566 | | | 455 | 470 | |
| | 480 | 480 | | | 389 | 510 | |
| | 449 | 439 | | | 394 | 379 | |
| | 424 | 399 | | | 449 | 470 | |
| | 395 | 430 | | | 450 | 440 | |
| **Average** | **443** | **457** | | **Average** | **433** | **449** | |

* Measurements for A & B were obtained separately

## Figure B10. DARROW Sensitivity Test (Grapple B51)

**Date:** 1/21/04
**Cricket System ID**: Darrow/Bill Hines/Grapple B51/Transmitter 5
**Test Source**: Cs-137, Activity 1.07 uCi, 8/8/84
**Weather Conditions:** Sunny, ~45-50 °F
**Performed By**: Ayman Shourbaji & Larry Phillips

| | Back Ground | |
|---|---|---|
| | **Det A** | **Det B** |
| | 56 | 45 |
| | 40 | 51 |
| | 76 | 40 |
| | 91 | 56 |
| | 71 | 51 |
| **Average** | **67** | **49** |

| See Sketch #1 for Measurement Locations | | | | | |
|---|---|---|---|---|---|
| **A1** | **A2** | **A3** | **B1** | **B2** | **B3** |
| 359 | 561 | 556 | 258 | 545 | 449 |
| 338 | 702 | 636 | 202 | 601 | 566 |
| 450 | 667 | 581 | 318 | 571 | 465 |
| 313 | 530 | 616 | 232 | 435 | 389 |
| 374 | 550 | 517 | 187 | 550 | 455 |
| 268 | 651 | 596 | 253 | 470 | 409 |
| 328 | 535 | 515 | 308 | 545 | 384 |
| 389 | 601 | 550 | 278 | 495 | 520 |
| 318 | 561 | 626 | 247 | 535 | 465 |
| 283 | 540 | 621 | 258 | 545 | 394 |
| **342** | **590** | **581** | **254** | **529** | **450** |

| See Sketch #1 for Measurement Locations | | | |
|---|---|---|---|
| **C0 (T)** | **C6 (T)** | **C12 (T)** | **C18(T)** |
| 415 | 414 | 441 | 338 |
| 413 | 416 | 404 | 341 |
| 409 | 414 | 401 | 339 |
| 408 | 416 | 400 | 335 |
| 407 | 405 | 398 | 336 |
| 404 | 408 | 397 | 338 |
| 406 | 411 | 392 | 336 |
| 404 | 410 | 390 | 332 |
| 399 | 408 | 386 | 329 |
| 401 | 407 | 383 | 330 |
| **407** | **411** | **399** | **335** |

C0 (T) denotes measurement taken at point C w/ source placed against the detector and readings taken from channel T

C6 (T) denotes measurement taken at point C w/ source 6" from the detector and readings taken from channel T

C12 (T) denotes measurement taken at point C w/source 12" from the detecor and readings taken from channel T.

C18 (T) denotes measurement taken at point C w/source 18" from the detecor and readings taken from channel T.

## Figure B11. CHARLESTON ALARM RESPONSE TEST
## GRAPPLE #1

**Date:** 5/26/2004
**Cricket System ID** Charleston/Crane #3/Grapple #1(10 yards)/Transmitter #2
**Test Source** 2 Custom Built Thoriated Welding Rods (50 uR/hr each)
**Weather Conditions:** Sunny, ~90°F
**Performed By** Ayman Shourbaji & Larry Phillips

| | Background | | |
|---|---|---|---|
| | A | B | T |
| | 56 | 35 | 109 |
| | 66 | 56 | 107 |
| | 48 | 46 | 108 |
| | 45 | 56 | 106 |
| | 56 | 51 | 105 |
| | 61 | 61 | 105 |
| | 56 | 71 | 104 |
| | 35 | 35 | 103 |
| | 51 | 25 | 104 |
| | 71 | 35 | 103 |
| **Average** | **55** | **47** | **105** |

| | Tines Open | | Tines Closed | | Remark |
|---|---|---|---|---|---|
| | A (Net CPS) | B (Net CPS | A (Net CPS | B (Net CPS) | |
| | 820 | 882 | 678 | 534 | All Alarms |
| | 885 | 806 | 754 | 650 | LVL1 #RAB |
| | 941 | 857 | 850 | 675 | |
| | 764 | 897 | 916 | 867 | |
| | 779 | 928 | 850 | 837 | |
| | 704 | 918 | 794 | 1044 | |
| | 724 | 938 | 769 | 882 | |
| | 587 | 812 | 724 | 832 | |
| | 592 | 806 | 623 | 968 | |
| | 158 | 852 | 315 | 931 | |
| **Average** | **695** | **870** | **727** | **822** | |

### CHARLESTON SENSITIVITY TEST

| A1(Net cps) | A2 (Net cps) | A3 (Net cps) | B1(Net cps) | B2(Net cps) | B3 (Net cps) | C0(T) (Net cps) | C6(T) (Netcps) | C12(T) (Net cps) |
|---|---|---|---|---|---|---|---|---|
| 608 | 855 | 542 | 569 | 928 | 835 | 310 | 472 | 340 |
| 789 | 799 | 592 | 665 | 817 | 716 | 303 | 473 | 345 |
| 628 | 754 | 577 | 594 | 806 | 837 | 299 | 475 | 345 |
| 739 | 845 | 496 | 756 | 781 | 568 | 299 | 474 | 350 |
| 704 | 840 | 512 | 589 | 786 | 620 | 298 | 479 | 354 |
| 587 | 729 | 572 | 610 | 892 | 655 | 296 | 481 | 356 |
| 648 | 835 | 547 | 645 | 913 | 700 | 295 | 478 | 359 |
| 688 | 739 | 557 | 640 | 968 | 574 | 293 | 477 | 366 |
| 592 | 789 | 567 | 625 | 923 | 736 | 292 | 476 | 369 |
| 754 | 693 | 512 | 564 | 867 | 690 | 289 | 476 | 375 |
| **673** | **787** | **547** | **626** | **868** | **693** | **297** | **476** | **356** |

## Figure B12. CHARLESTON ALARM RESPONSE TEST
## GRAPPLE #2

**Date:** 5/26/2004
**Cricket System ID** Charleston/Crane #3/Grapple #2 (12 yards)/Transmitter #2
**Test Source**: 2 Custom Built Thoriated Welding Rods (50 uR/hr each)
**Weather Conditions:** Sunny, ~90 °F
**Performed By**: Ayman Shourbaji & Larry Phillips

| | Background | | |
|---|---|---|---|
| | A | B | T |
| | 56 | 35 | 109 |
| | 66 | 56 | 107 |
| | 48 | 46 | 108 |
| | 45 | 56 | 106 |
| | 56 | 51 | 105 |
| | 61 | 61 | 105 |
| | 56 | 71 | 104 |
| | 35 | 35 | 103 |
| | 51 | 25 | 104 |
| | 71 | 35 | 103 |
| **Average** | **55** | **47** | **105** |

| | Tines Open | | Tines Closed | | Remark |
|---|---|---|---|---|---|
| | A (Net CPS) | B (Net CPS) | A (Net CPS) | B (Net CPS) | |
| | 668 | 428 | 683 | 453 | All Alarms |
| | 643 | 519 | 623 | 443 | LVL1 #RAB |
| | 623 | 478 | 618 | 423 | |
| | 587 | 498 | 496 | 428 | |
| | 486 | 503 | 512 | 468 | |
| | 507 | 256 | 446 | 301 | |
| | 461 | 317 | 446 | 231 | |
| | 451 | 342 | 385 | 337 | |
| | 582 | 382 | 456 | 307 | |
| | 527 | 428 | 491 | 302 | |
| **Average** | **553** | **415** | **515** | **369** | |

### CHARLESTON SENSITIVITY TEST

| A1(Net cps) | A2 (Net cps) | A3 (Net cps) | B1(Net cps) | B2(Net cps) | B3 (Net cps) | C0(T) (Net cps) | C6(T) (Netcps) | C12(T) (Net cps) |
|---|---|---|---|---|---|---|---|---|
| 224 | 688 | 603 | 332 | 604 | 408 | 254 | 328 | 253 |
| 163 | 653 | 653 | 357 | 509 | 347 | 259 | 330 | 252 |
| 183 | 577 | 618 | 413 | 589 | 392 | 261 | 329 | 250 |
| 219 | 734 | 638 | 377 | 574 | 428 | 263 | 327 | 249 |
| 289 | 759 | 663 | 473 | 559 | 347 | 267 | 328 | 247 |
| 178 | 870 | 658 | 367 | 670 | 362 | 271 | 331 | 250 |
| 239 | 663 | 542 | 372 | 579 | 458 | 273 | 334 | 251 |
| 284 | 724 | 648 | 408 | 458 | 372 | 274 | 332 | 252 |
| 289 | 709 | 698 | 367 | 483 | 281 | 272 | 331 | 246 |
| 305 | 749 | 608 | 423 | 514 | 408 | 269 | 330 | 247 |
| **237** | **712** | **632** | **389** | **554** | **380** | **266** | **330** | **249** |

## Figure B13. CHARLESTON ALARM RESPONSE TEST
## GRAPPLE #3

**Date:** 5/26/2004
**Cricket System ID** Charleston/Crane #3/Grapple #3 (12 yards)/Transmitter #2
**Test Source** 2 Custom Built Thoriated Welding Rods (50 uR/hr each)
**Weather Conditions:** Sunny, 90°F
**Performed By** Ayman Shourbaji & Larry Phillips

| | Background | | |
|---|---|---|---|
| | A | B | T |
| | 56 | 35 | 109 |
| | 66 | 56 | 107 |
| | 48 | 46 | 108 |
| | 45 | 56 | 106 |
| | 56 | 51 | 105 |
| | 61 | 61 | 105 |
| | 56 | 71 | 104 |
| | 35 | 35 | 103 |
| | 51 | 25 | 104 |
| | 71 | 35 | 103 |
| **Average** | **55** | **47** | **105** |

| | Tines Open | | Tines Closed | | Remark |
|---|---|---|---|---|---|
| | A (Net CPS) | B (Net CPS | A (Net CPS) | B (Net CPS | |
| | 522 | 564 | 522 | 756 | All Alarms |
| | 512 | 675 | 481 | 539 | LVL1 #RAB |
| | 547 | 700 | 557 | 630 | |
| | 618 | 615 | 587 | 771 | |
| | 456 | 625 | 623 | 635 | |
| | 476 | 685 | 597 | 655 | |
| | 376 | 594 | 643 | 584 | |
| | 355 | 579 | 587 | 620 | |
| | 300 | 640 | 416 | 549 | |
| | 274 | 519 | 365 | 514 | |
| **Average** | **443** | **620** | **537** | **625** | |

### CHARLESTON SENSITIVITY TEST

| A1 (Net cps) | A2(Net cps) | A3(Net cps) | B1(Net cps) | B2(Net cps) | B3(Net cps) | C0(T)(Net cps) | C6(T)(Net cps) | C12(T)(Net cps) |
|---|---|---|---|---|---|---|---|---|
| 279 | 613 | 474 | 423 | 579 | 610 | 218 | 404 | 221 |
| 264 | 683 | 562 | 367 | 569 | 579 | 216 | 401 | 288 |
| 274 | 673 | 436 | 332 | 559 | 579 | 213 | 400 | 284 |
| 285 | 572 | 476 | 347 | 660 | 675 | 214 | 389 | 283 |
| 365 | 719 | 562 | 327 | 655 | 498 | 209 | 387 | 284 |
| 310 | 648 | 633 | 246 | 680 | 578 | 208 | 386 | 287 |
| 234 | 613 | 502 | 236 | 569 | 630 | 209 | 358 | 285 |
| 269 | 643 | 512 | 317 | 640 | 610 | 207 | 385 | 284 |
| 239 | 638 | 582 | 357 | 604 | 604 | 209 | 386 | 285 |
| 305 | 678 | 491 | 438 | 625 | 660 | 213 | 390 | 287 |
| **282** | **648** | **523** | **339** | **614** | **602** | **211** | **388** | **278** |

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